NeoBiota 50: 109–122 (2019)
doi: 10.3897/neobiota.50.35466
http://neobiota.pensoft.net

PROJECT DESCRIPTION

A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

InvasiBES: Understanding and managing the impacts of Invasive alien species on Biodiversity and Ecosystem Services

Belinda Gallardo[1,2], Sven Bacher[3], Bethany Bradley[4], Francisco A. Comín[1], Laure Gallien[5], Jonathan M. Jeschke[6,7,8], Cascade J. B. Sorte[9], Montserrat Vilà[10]

1 *Department of Biodiversity Conservation, Pyrenean Institute of Ecology (IPE-CSIC), Avda Montañana 1005, 50059 Zaragoza, Spain* **2** *Department of Zoology, University of Cambridge, Downing St. CB23EJ, Cambridge, UK* **3** *Department of Biology, University of Fribourg, Chemin du Musée 10, 1700 Fribourg, Switzerland* **4** *Department of Environmental Conservation, University of Massachusetts, Amherst, MA 01003 USA* **5** *LECA (Laboratoire d'Ecologie Alpine), University of Grenoble Alpes, University of Savoie Mont Blanc, CNRS, 38000 Grenoble, France* **6** *Freie Universität Berlin, Department of Biology, Chemistry, Pharmacy, Institute of Biology, Königin-Luise-Str. 1-3, 14195 Berlin, Germany* **7** *Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Müggelseedamm 310, 12587 Berlin, Germany* **8** *Berlin-Brandenburg Institute of Advanced Biodiversity Research (BBIB), Altensteinstr. 34, 14195 Berlin, Germany* **9** *Department of Ecology & Evolutionary Biology, University of California, Irvine, CA 92697 USA* **10** *Doñana Biological Station (EBD-CSIC), Avda Américo Vespucio 26, Isla de la Cartuja, 41092 Sevilla, España*

Corresponding author: *Belinda Gallardo* (belinda@ipe.csic.es; galla82@hotmail.com; bg306@cam.ac.uk)

Academic editor: *Philip Hulme* | Received 7 May 2019 | Accepted 29 August 2019 | Published 14 October 2019

Citation: Gallardo B, Bacher S, Bradley B, Comín FA, Gallien L, Jeschke JM, Sorte CJB, Vilà M (2019) InvasiBES: Understanding and managing the impacts of Invasive alien species on Biodiversity and Ecosystem Services. NeoBiota 50: 109–122. https://doi.org/10.3897/neobiota.50.35466

Abstract

Invasive Alien Species (IAS) are amongst the most significant drivers of species extinction and ecosystem degradation, causing negative impacts on ecosystem services and human well-being. InvasiBES, a project funded by BiodivERsA-Belmont Forum for 2019–2021, will use data and models across scales, habitats and species to understand and anticipate the multi-faceted impacts of IAS and to provide tools for their management. Using Alien Species Narratives as reference, we will design future intervention scenarios focused on prevention, control and eradication of IAS in Europe and the United States, through a participatory process bringing together the expertise of scientists and stakeholders. We will also adapt current impact assessment protocols to assess both the detrimental and beneficial impacts of IAS on biodiversity and ecosystem services. This information will then be combined with maps of the potential distribution of Invasive Species of Interest in Europe under current and future climate-change scenarios. Likewise, we will

anticipate areas under risk of invasion by range-shifting plants of concern in the US. Finally, focusing on three local-scale studies that cover a range of habitats (freshwater, terrestrial and marine), invasive species (plants and animals) and ecosystem services (supporting, provisioning, regulating and cultural), we will use empirical field data to quantify the real-world impacts of IAS on biodiversity and ecosystem services and calculate indicators of ecosystem recovery after the invader is removed. Spatial planning tools (InVEST) will be used to evaluate the costs and benefits of species-specific intervention scenarios at the regional scale. Data, models and maps, developed throughout the project, will serve to build scenarios and models of biodiversity and ecosystem services that are relevant to underpin management of IAS at multiple scales.

Keywords

alien species, biodiversity, climate change, ecosystem services, management scenarios, Nature's Contribution to People, non-native species, participatory planning, risk assessment, species distribution models.

Introduction

Biological invasions are considered a direct driver of biodiversity loss and have pronounced negative impacts on supporting, provisioning, regulating and cultural services (Vilà and Hulme 2016). Both the numbers and distributions of invasive species are increasing in many parts of the world (Seebens et al. 2017), to the extent that the biogeographic distinctiveness of different regions is becoming blurred (Capinha et al. 2015). The costs of invasive species, currently estimated at €12.5 to 20 billion per year in Europe (Kettunen et al. 2008) and $120 billion per year in the US (Pimentel et al. 2005), are likely underestimated and will escalate with time (Bradshaw et al. 2016). These costs mostly arise from economic loss in the agriculture, forestry, energy and health sectors, diminished delivery of ecosystem services and cost of controlling and eradicating unwanted species. Past research on biological invasions has mainly focused on the ecological factors determining the species success and distribution, treating ecosystem services only marginally and focusing on particular species, habitats or ecosystem functions, such as nutrient and water cycling. Moreover, current knowledge on the impacts of biological invasions on ecosystem services is strongly biased towards terrestrial habitats and services that have marketable values (agriculture yields, forestry production, human health), whereas aquatic habitats and non-marketable services are largely ignored (Vilà and Hulme 2016). By synthesising knowledge across habitats (terrestrial, freshwater and marine) and scales (continental to local), the project InvasiBES (http://elabs.ebd.csic.es/web/invasibes), funded through the 2017–2018 Joint BiodivERsA-Belmont Forum Call on "Biodiversity Scenarios and Ecosystem Services", aims to provide a comprehensive understanding of the multi-faceted impacts of biological invasions on biodiversity and ecosystem services. Within this general framework, InvasiBES has identified a number of research needs associated with invasive species and ecosystem services.

The challenges posed by biological invasions in a global-change context have prompted a strong policy response at international and national levels (Turbelin et al. 2016). To support new regulations, researchers have developed standard protocols to systematically evaluate and prioritise impacts, including the *Environmental Impact Classification of Alien Taxa*-EICAT (Blackburn et al. 2014; Hawkins et al. 2015) for bi-

odiversity and the *Socio-Economic Impact Classification of Alien Taxa*-SEICAT (Bacher et al. 2017) for human well-being. Such tools are fundamental to evaluate the costs and benefits of plausible intervention scenarios to maintain ecosystem services. This is especially important in cases where invaders are perceived by society as having both positive and negative impacts, depending on the sector under consideration (e.g. invasive plants increase forage production but reduce pollination) or when management options are controversial due to ethical concerns (e.g. culling introduced animals) or for economic reasons (e.g. if cost-effectiveness of management actions is unclear, such as when the species is already widespread). InvasiBES will evaluate the beneficial and detrimental impacts of invasive species for an unbiased evaluation of the costs and benefits for society and ecosystems of intervention scenarios. This knowledge is fundamental for designing pro-active management plans that can effectively address the invasion threat.

Climate change introduces an additional challenge for management because species' ranges are shifting in response to warming temperatures (Walther et al. 2009). Climate change is expected to alter the vectors and pathways of invasion, enabling some species to expand into regions where they previously could not survive and reproduce (Dukes and Mooney 1999). Unprecedented arrivals of new colonisers, as well as range expansions of established invaders, are thus expected. Yet, which species, regions and ecosystem services will be most affected by climate change remains unknown. At the same time, climate change modelling provides a unique opportunity to identify areas under risk, thereby preventing and eradicating range-shifting species before they become widespread and problematic. The intervention scenarios envisioned by InvasiBES will consider the interactions between invasive species and climate change to ensure the most effective protection of biodiversity and ecosystem services in the context of global change.

Continental assessments of invasion risk are useful to guide trans-national policy development. However, the impacts caused by biological invasions on ecosystem services are strongly context-dependent, varying markedly between species and habitats (Kumschick et al. 2015). To support local-scale management, quantifying how ecosystem services differ in invaded *vs.* uninvaded sites across a range of systems is critical. Moreover, local-scale analysis provide a means to explore the degree of ecosystem recovery once the species has been removed, which is a key aspect to risk assessment that is difficult to determine. Focusing on three local-scale studies that cover a range of habitats (freshwater, terrestrial and coastal), invasive species (plants and animals) and ecosystem services (supporting, provisioning, regulating and cultural), InvasiBES will use field data to evaluate the real-world costs and benefits of IAS management.

Objectives

In the framework of the research needs identified above, the InvasiBES objectives are to:

- Develop intervention scenarios of invasive species management in Europe and the US. These intervention scenarios will be representations of possible futures that evaluate the effects of alternative management options and levels of policy implementation.

- Adapt and test impact assessment protocols to consider both the beneficial and detrimental effects of non-native species on biodiversity and ecosystem services.
- Evaluate current and future impacts of key invasive species of interest on biodiversity and ecosystem services in Europe and the US.
- Evaluate the effects of particular invasive species on biodiversity and ecosystem services at the local to regional scale and compare them with previous continental assessments.

Structure

Employing a multi-disciplinary combination of techniques, the objectives of InvasiBES are addressed in five interlinked work packages (Fig. 1).

WP 1. Participatory planning and evaluation of scenarios of invasive species and ecosystem services

The main objective of this work package (WP) is to develop future intervention scenarios of invasive species management together with other scientists and stakeholders through a process of Participatory Scenario Planning (PSP). This is an increasingly used tool that facilitates exploration of the future evolution of complex systems, thereby providing information for decision-making (Palomo et al. 2017). First, we will select a number of Invasive Species of Interest in Europe and the United States that will be the focus of research in the following WPs. In Europe, between 20 and 50 species will be selected to cover various habitats (freshwater, terrestrial, marine), stages of invasion (non-established through to widespread) and impacts (Minimal to Massive, positive and negative). The selection of species will accommodate the research needs of all WPs, which may focus on subsets of the species list, depending on the WP's objectives, data and resources availability. Priority will be given to species already included or expected to be included in the "List of IAS of EU concern", a list of 49 (+18 candidates) plants and animals whose management has been prioritised by the European Union under Regulation 1143/2014. In the absence of similar official species listings in the US, we will first collate information about the impacts of invasive species on biodiversity and ecosystem services with EICAT and then select 100 high-risk plants and marine organisms.

Intervention scenarios will use as reference the Alien Species Narratives (ASNs), developed by AlienScenarios (https://alien-scenarios.org/, Essl et al. 2019), another BiodivERsA-Belmont Forum project closely related to InvasiBES. ASNs are qualitative narratives of plausible futures of global invasive species richness (Lenzner et al. 2019) that will serve as a framework to explore the impacts of different levels of policy implementation. For InvasiBES, we envision two extreme possible intervention situations: under a *worst-case* scenario, invasive species are not managed and, by 2050, they are able to fill their potential climate range modelled in WPs 3 and 4, fostered by increas-

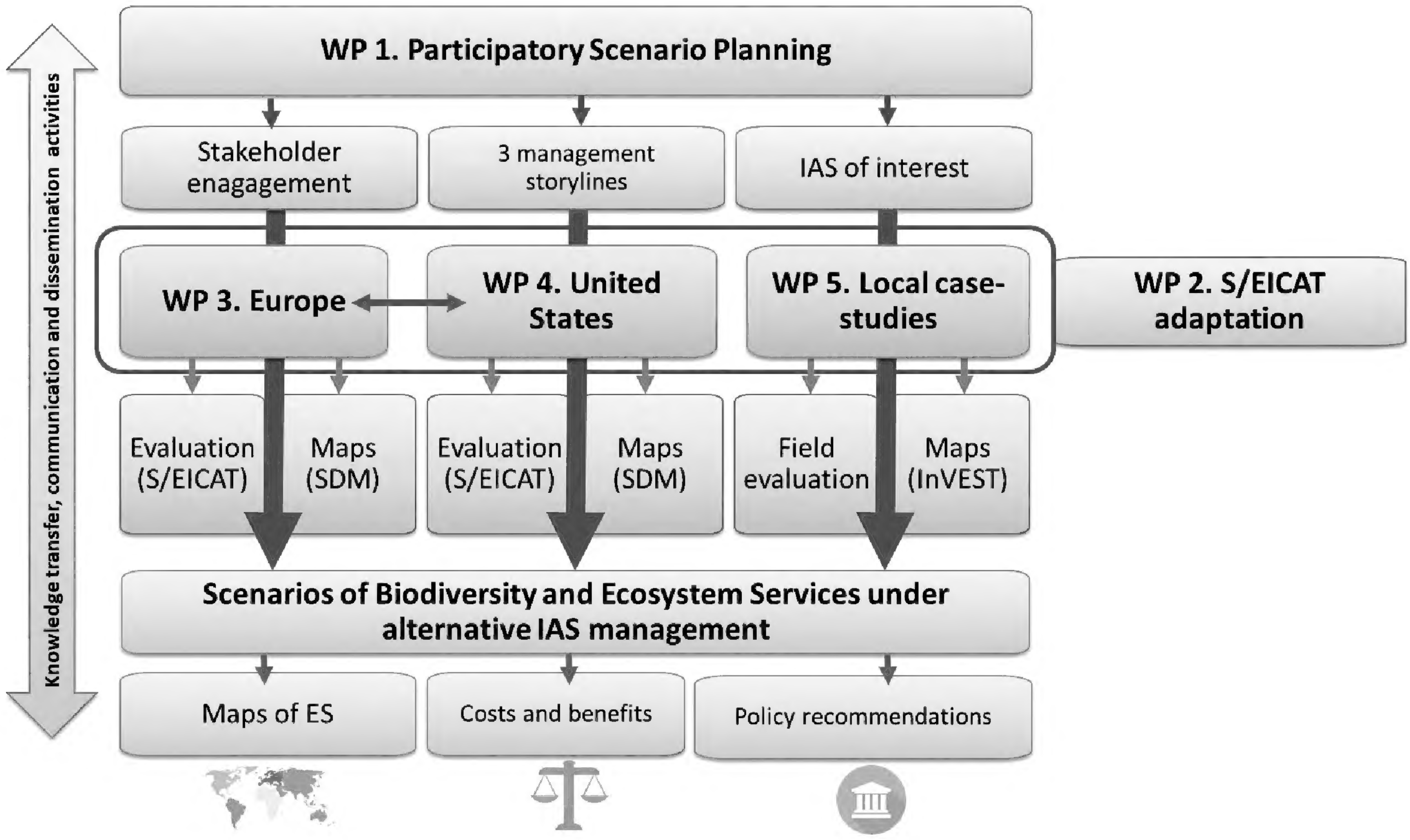

Figure 1. InvasiBES aims to use scenarios and models to understand and manage the impacts of Invasive Alien Species on biodiversity and ecosystem services. First, we will develop intervention scenarios with other scientists and stakeholders and select Invasive Species of Interest for the project (WP 1). Second, we will use standard protocols such as EICAT and SEICAT (S/EICAT) to evaluate the impacts of species on biodiversity and ecosystem services (WP 2). This information will then be combined with species distribution models (SDM) under current and future climate conditions in Europe and the US (WP3-4). Local-scale studies combining field data and scenario generation (through InVEST) will be used to evaluate the real-world costs and benefits of IAS management (WP5). Deliverables of the project include spatially-explicit assessments of the threat posed by invasive species to biodiversity and ecosystem services under a range of climate-change and intervention scenarios.

ing globalisation. Under a *best-case* scenario, international co-ordinated actions prevent the arrival of new invaders – through, for instance, border control and trade regulations – and existing invasive species are managed via eradication techniques and ecological restoration. In between, a number of scenarios can be drawn, ideally through a participatory process involving stakeholders with practical experience in environmental management and ecosystem restoration. In all cases, intervention scenarios will consider all stages of the invasion process and the cost-effectiveness, practicality and acceptability of alternative management options (following Booy et al. 2017).

WP 2. Evaluating the positive and negative impacts of invasive species on biodiversity and ecosystem services

The main objective of this WP is to adapt and validate impact assessment protocols considering both the detrimental and beneficial impacts of invasive species on biodiversity and ecosystem services. The impact assessment protocol, EICAT (Blackburn et al. 2014; Hawkins et al. 2015) – and its adaptation to include socio-economic im-

pacts, SEICAT (Bacher et al. 2017) – will be used to score impacts on biodiversity and ecosystem services of Invasive Species of Interest in five levels, from Minimal Concern to Massive. For example, provisioning ecosystem services are considered in SEICAT through impacts on "*Material and immaterial assets*" (e.g. agriculture, fisheries etc.), supporting ecosystem services are captured in EICAT mechanisms "*Chemical, physical or structural impact on ecosystems*" and cultural ecosystem services through SEICAT "*Social, spiritual and cultural relations*". EICAT has the advantage that it has been adopted by the IUCN and, thus, our implementation at the continental scale can be used as a proof-of-concept for international adoption of the protocol.

Both EICAT and SEICAT (S/EICAT hereafter) classifications include estimations of uncertainty, but currently consider only detrimental impacts. In this project, we aim to adapt them to also quantify beneficial impacts (e.g. providing food for native species or humans, cultural values as recreational fishing and hunting) that are important to resolve management conflicts. We aim to measure positive impacts at a similar 5-point scale as detrimental impacts (e.g. by quantifying how much native species or human activities benefit from the presence of an invasive species), plus a 3-point scale uncertainty estimation (low-medium-high). Such consistency will facilitate the comparison of detrimental and beneficial impacts. We will test the adaptation using the Invasive Species of Interest selected in WP1 across a wide range of taxa and habitats. We will ensure that the selection of species for testing will include species with presumably detrimental and beneficial impacts.

WP 3. Modelling and mapping the impacts of invasive species on biodiversity and ecosystem services in Europe

Under the framework of this WP, we will model and map the potential impacts of Invasive Species of Interest on biodiversity and ecosystem services in Europe under current and future 2050 climate-change scenarios. Distribution modelling techniques already employed in Gallardo et al. (2017) will be used to correlate the presence of Invasive Species of Interest in Europe with the environmental conditions of their native and introduced range. We will use these models to predict the expansion of species under current and future 2050 scenarios, identifying regions of maximum concern because of their susceptibility towards invasion. SDMs will account for uncertainty in data availability through: i) bias-analyses of occurrence data; ii) modelling approach, through the use of ensemble models combining multiple modelling settings; and iii climate change forecasts, by exploring multiple IPCC scenarios.

Potential impacts of invasive species will be calculated by integrating species-specific S/EICAT scores with maps of predicted distributions and ecosystem services supply. To that end, we will build on the approach used by Nentwig et al. (2010) to assess the ecological and economic impacts of invasive mammals in Europe. First, we will gather from literature the existing maps reflecting ecosystem services (e.g. pollination, leisure, water purification, all available at European scale through the Joint Research Centre, https://data.jrc.ec.europa.eu/) and/or target assets (e.g. human population density in the case

of invaders causing human health problems) that are directly affected by Invasive Species of Interest. Then we will combine distribution maps of species affecting a particular ecosystem service/asset to identify areas with high provision-high risk of invasion. As the impacts of invasive species are highly context-dependent, we will necessarily assume that the potential impacts of selected invaders are similar across Europe, a precautionary principle common in invasion biology. Local case studies (WP5) will better explore the spatio-temporal variability of impacts and allow comparing projections across scales.

Finally, we will use the Non-Native Risk Management (NNRM) scheme of Booy et al. (2017) to translate the general intervention scenarios developed in WP1 into species-specific scenarios. This scheme provides a structured evaluation of management options for current and future invasive species that, similar to S/EICAT, uses semi-quantitative responses and uncertainty scores to assess seven feasibility criteria: effectiveness, practicality, cost, impact, acceptability, opportunity and likelihood of re-invasion. We will finally compare the potential costs and benefits of alternative intervention scenarios in terms of biodiversity and ecosystem services.

Data, maps and models generated in this package will provide spatially-explicit estimations of the threats posed by IAS to biodiversity and ecosystem services in Europe and their potential evolution under a range of climate and management scenarios.

WP 4. Assessing and mapping the impacts of invasive species on biodiversity and ecosystem services in the US

In this WP, we will identify range-shifting invasive plants that have not yet been reported in parts of the US but are projected to expand with climate change. This will help anticipating the threat posed by invasive species to biodiversity and ecosystem services under alternative intervention scenarios. We will first develop a database synthesising all ecological, agricultural, economic and human health impacts reported in the scientific literature and use S/EICAT protocols to evaluate impacts. Then we will capitalise on available occurrence data to model the potential distribution of ca. 100 range-shifting invasive plants. This approach is focused on emergent threats, whereas established species with the potential to become invasive under climate change, often called sleeper species (Crooks 2005), are out of the scope of this project.

WP 5. Impacts of invasive species on biodiversity and ecosystem services at the local scale

This WP aims to advance the empirical understanding of invasive species impacts on biodiversity and ecosystem services and their context-dependency. At the local scale, a number of invaded and uninvaded sites across freshwater, terrestrial and marine habitats will be selected to measure impacts on biodiversity and ecosystem services (Table 1). In addition, physical removal experiments with minimal disturbance to non-target species will be used to follow changes in ecosystem properties after resto-

Table 1. Characteristics of local scale studies foreseen in WP5.

Habitat	Location	Targeted invasive species	Targeted ecosystem services	Control techniques
Freshwater	Lower Ebro River and delta, NE Spain	Freshwater invertebrates (*Pomacea* spp., *Callinectes sapidus*)	Supporting (biodiversity maintenance), regulating (water quality), provisioning (food provision) and cultural (aesthetic, recreation)	Physical removal Exclusion experiments
Terrestrial	Grasslands, SE France	Terrestrial plants (*Solidago gigantea*, *Impatiens glandulifera*)	Regulating (pollination, biodiversity maintenance), supporting (carbon storage) and provisioning (forage production)	Physical removal experiments
Marine	Marine habitats, California, USA	Marine invertebrates (*Watersipora subtorquata*, *Mexacanthina lugubris*)	Supporting (habitat quality and biodiversity maintenance), regulating (carbon sequestration and water quality), provisioning (food production) and cultural (aesthetic, recreation and environmental education)	Physical removal experiments

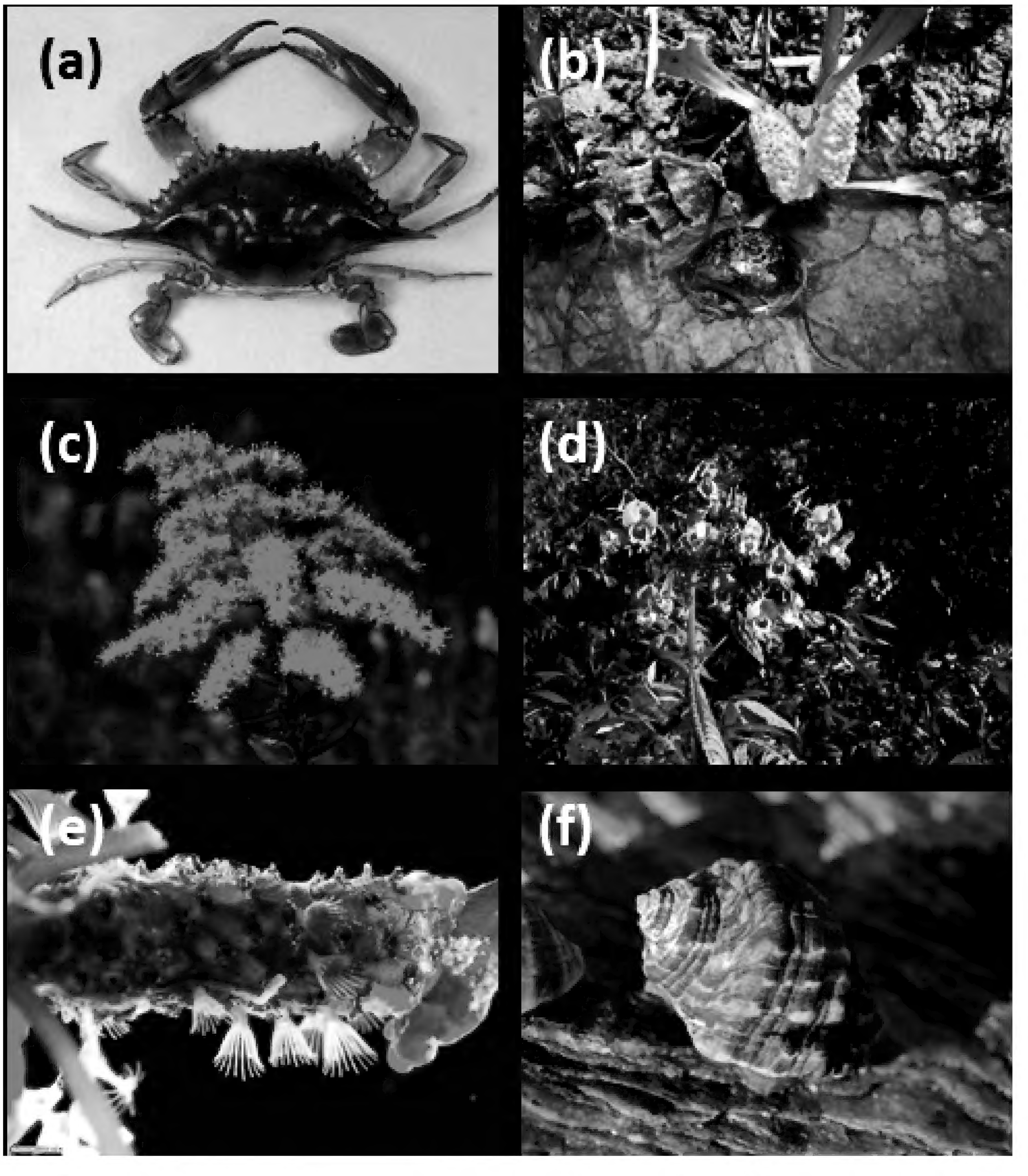

Figure 2. Focal invasive species that will be investigated during InvasiBES in three local case studies planned in the Ebro River (Spain) (**a**) the blue crab (*Callinectes sapidus*) and (**b**) apple snail (*Pomacea canaliculata*); the French Alps lowlands (**c**) the Canadian goldenrod (*Solidago canadensis*) and (**d**) Himalayan Balsam (*Impatiens glandulifera*); and in marine habitats of California (**e**) the red-rust bryozoan (*Watersipora subtorquata*) and (**f**) the dark unicorn sea snail (*Mexacanthina lugubris*). (All photos licensed through CC BY-SA 3.0).

ration. Our aim is to measure biodiversity and ecosystem services under the general assumption that restored sites will fall somewhere in between invaded and uninvaded treatments. This simple assumption has been rarely tested in the field, but plays an important role in differentiating major from massive impacts in S/EICAT protocols. Finally, we will use the software InVEST (https://naturalcapitalproject.stanford.edu/invest/) to spatially model the provision of ecosystem services, biodiversity and trade-offs at the local/regional scale (Nelson et al. 2009). All species sampled in WP5 will be modelled in WP3-4, evaluated with S/EICAT (WP2) and considered in the elaboration of management scenarios (WP1). In contrast to the continental evaluations of WPs 3 and 4, case studies will provide real on-the-ground information to test the accuracy of impact assessments like S/EICAT and to quantify the real costs and benefits of alternative management decisions. While case studies share a common work plan for the evaluation of impacts, the specific field methodologies differ depending on the habitat, invasive species and ecosystem services targeted in each case.

Case study 1-Freshwater ecosystems. We will focus on two recent invaders of the Ebro River and Delta (NE, Spain): the apple snail (*Pomacea canaliculata* Lamark, 1928) and the blue crab (*Callinectes sapidus* Rathbun, 1896). The apple snail, accidentally introduced in the area in 2010 (López et al. 2010), consumes vast amounts of rice and can devastate the flora and fauna of natural wetlands, with important impacts on food provisioning, nutrient cycling and primary productivity (EFSA Panel on Plant Health 2014). It is still spreading in the Ebro Delta despite the control and eradication measures implemented in rice paddies and the river channel (physical removal). The blue crab, also present in the Ebro Delta since 2013, is an omnivore able to feed on plants and animals, including apple snails, but it is also an important fishing resource with economic value. Therefore, this species has both negative (reduced biodiversity, changes in habitat structure) and positive (biological control, fishing resource) impacts on ecosystem services. Both species are being managed in parts of the lower Ebro River, which will facilitate the selection of invaded, uninvaded and restored plots under similar environmental and anthropogenic conditions. The work-plan includes 15 sampling stations per treatment (invaded, uninvaded and restored, total N = 45 per species) where we will determine the density and population structure of the invader. We will also take water, sediment and macroinvertebrate samples to calculate indicators of ecosystem services. The sampling campaign will be repeated at least twice (2019 and 2020) with the possibility of a third campaign in 2021. The impacts of the blue crab may be more difficult to assess because it is a highly mobile and territorial species. For this reason, we will consider using enclosures to further investigate changes in ecosystem services caused by the blue crab. With this information, we will finally employ the software InVEST to explore spatially how alternative intervention scenarios may affect ecosystem services at the local scale.

Case study 2-Terrestrial ecosystems. We will focus on two terrestrial plants that are highly invasive in semi-natural meadows and forest edges across Europe: the Canadian goldenrod (*Solidago canadensis* L.) and the Himalayan Balsam (*Impatiens glandulifera* Royle). The impacts on biodiversity and ecosystem services of these two invasive plants will be studied in detail in two nature reserves located in the French Alps

lowlands: the "Reserve du Bout du Lac d'Annecy" and the "Marais de Giez". These two species and two natural reserves are particularly interesting because of their joint conservation and agricultural values. From the conservation perspective, these nature reserves are protecting hyper-sensitive habitats that harbour rare and protected species, which are now threatened by the presence of mono-specific stands of the two plant invaders. From the agricultural perspective, the eradication of the invaders is highly contested by farmers and beekeepers of the region who benefit from the high quantity of pollen they produce. It is thus important to clarify the real positive and/or negative impacts of Canadian goldenrod and Himalayan balsam on regulation (plant diversity and pollination), supporting (carbon storage) and provisioning (forage production) services. These impacts will be quantified from field observations along a gradient of invasion: from non-invaded sites to gradually more invaded sites, up to near-mono-specific stands. Eradication of these plants is not feasible in protected areas with limited application of herbicides. For this reason, we will explore the possibility of conducting laboratory experiments for physical removal.

Case study 3-Marine ecosystems. The choice of marine study species will be based on the results of our literature review, in which we will look for studies reporting distributions, abundances and per capita effects of range-expanding species and the > 250 alien marine species reported in California (https://www.wildlife.ca.gov/OSPR/Science/Cal-NEMO). Target species will be chosen based on their current occurrence in southern California and lack of previous studies, despite having high potential for impacts based on their abundance, range size, expected strength of community interactions and functional relationships to other impacting species (Parker et al. 1999; Thomsen et al. 2014). Potential candidates for this study include sub-tidal epibenthic invertebrates in the "fouling" community (such as the bryozoan *Watersipora subtorquata* d'Orbigny, 1852) and consumers, including the intertidal, range-expanding whelk *Mexacanthina lugubris* (G. B. Sowerby I, 1822). We will quantify impacts using field observations across gradients in invader abundance, field physical removal experiments and lab experiments to resolve community interactions and ecosystem dynamics, such as effects on water quality. Sampling sites will be chosen to share similar environmental and disturbance conditions to avoid confounding factors. These marine invasive species are likely to play supporting (habitat quality and biodiversity maintenance), regulation (carbon sequestration and water quality), provisioning (food production) and cultural (aesthetic, recreation and environmental education) roles in local ecosystems.

Outlook

The project InvasiBES is designed to provide direct support to the implementation of national and international regulations of invasive species in Europe and the US, as well as to make progress towards accomplishing the targets of the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011–2020 (Aichi Target #9: "By 2020

[…], priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment"), the UN's 2030 Agenda for Sustainable Development (Goal #15.8: "By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species") and the EU Regulation 1143/2014 on IAS that aims to establish rules to prevent, minimise and mitigate adverse effects of invasive species on biodiversity and related ecosystem services. In particular, InvasiBES will contribute towards accomplishing the needs of these international regulations through the development of intervention scenarios that evaluate the cost of inaction and the cost-effectiveness and socio-economic aspects of invasive species management (WP1). By considering multiple scenarios of climate change (WPs 3 and 4), the project will also provide insights into how different levels of commitment to the Paris Agreement on Climate Change may affect the expansion of invasive species and their impacts on biodiversity and ecosystem services. Furthermore, InvasiBES will prioritise species listed under EU regulation for analysis (WP3) and so European and member state policy-makers and practitioners are expected to be especially interested in the project and will be invited to engage in participatory scenario planning. In the US, we will collaborate with the Northeast Regional Invasive Species and Climate Change (RISCC, https://people.umass.edu/riscc/) Management Network and the North American Invasive Species Management Association (NAISMA, https://www.naisma.org/) to support the regulatory listing of high-priority species identified in this project (WP4). At national and local scales, InvasiBES will provide the best-available evidence and models to evaluate the costs and benefits of invasive species management (WP5), thereby helping to make decisions that are relevant for the conservation of biodiversity and ecosystem services. Ultimately, knowledge and data produced in the framework of this project will support the implementation of national and international policies, evaluate strategies and actions to the improve management of invasive species, mitigate any potential negative effects and, ultimately, promote sustainability.

Acknowledgements

InvasiBES was funded through the 2017–2018 Belmont Forum and BiodivERsA joint call for research proposals, under the BiodivScen ERA-Net COFUND programme and with the following funding organisations: the Spanish Ministry of Science, Innovation and Universities (PCI2018-092986 and PCI2018-092939, MCIU/AEI/FEDER, UE), the Swiss National Science Foundation (31BD30_184114 and 31003A_179491), the US National Science Foundation (ICER-1852326), the German Federal Ministry of Education and Research BMBF (01LC1803A), and the French National Research Agency (ANR-18-EBI4-0001-06). BG is currently supported by the Biosecurity Initiative at St. Catherine's, BioRISC (http://www.biorisc.com) and JMJ is additionally supported by the Deutsche Forschungsgemeinschaft DFG (JE 288/9-2).

References

Bacher S, Blackburn TM, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou A, Nentwig W, Pergl J, Pysek P, Rabitsch W, Richardson DM, Roy HE, Wolf-Christian S, Scalera R, Vilà M, Wilson JRU, Kumschick S (2017) Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution 9: 159–168. https://doi.org/10.1111/2041-210X.12844

Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Marková Z, Mrugała A, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, Wilson JRU, Winter M, Genovesi P, Bacher S (2014) A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts. PLoS Biol 12: e1001850. https://doi.org/10.1371/journal.pbio.1001850

Booy O, Mill AC, Roy HE, Hiley A, Moore N, Robertson P, Baker S, Brazier M, Bue M, Bullock R (2017) Risk management to prioritise the eradication of new and emerging invasive non-native species. Biological Invasions 19: 2401–2417. https://doi.org/10.1007/s10530-017-1451-z

Bradshaw CJA, Leroy B, Bellard C, Roiz D, Albert C, Fournier A, Barbet-Massin M, Salles J-M, Simard F, Courchamp F (2016) Massive yet grossly underestimated global costs of invasive insects. Nature Communications 7: 12986. https://doi.org/10.1038/ncomms12986

Capinha C, Essl F, Seebens H, Moser D, Pereira HM (2015) The dispersal of alien species redefines biogeography in the Anthropocene. Science 348: 1248–1251.https://doi.org/10.1126/science.aaa8913

Crooks JA (2005) Lag times and exotic species: The ecology and management of biological invasions in slow-motion. Ecoscience 12: 316–329. https://doi.org/10.2980/i1195-6860-12-3-316.1

Dukes JS, Mooney HA (1999) Does global change increase the success of biological invaders? Trends in Ecology & Evolution 14: 135–139. https://doi.org/10.1016/S0169-5347(98)01554-7

EFSA Panel on Plant Health (2014) Scientific Opinion on the environmental risk assessment of the apple snail for the EU. EFSA Journal 12: 3641. https://doi.org/10.2903/j.efsa.2014.3641

Essl F, Lenzner B, Courchamp F, Dullinger S, Jeschke JM, Kühn I, Leung B, Moser D, Roura-Pascual N, Seebens H (2019) Introducing AlienScenarios: a project to develop scenarios and models of biological invasions for the 21st century. NeoBiota 45: 1–17. https://doi.org/10.3897/neobiota.45.33366

Gallardo B, Aldridge DC, González-Moreno P, Pergl J, Pizarro M, Pyšek P, Thuiller W, Yesson C, Vilà M (2017) Protected areas offer refuge from invasive species spreading under climate change. Global Change Biology 23: 5331–5343. https://doi.org/10.1111/gcb.13798

Hawkins CL, Bacher S, Essl F, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Nentwig W, Pergl J, Pyšek P (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). Diversity and Distributions 21: 1360–1363. https://doi.org/10.1111/ddi.12379

Kettunen M, Genovesi P, Gollasch S, Pagad S, Starfinger U, ten Brink P, Shine C (2008) Technical support to EU strategy on invasive species (IS) – assessment of the impacts of IS in Europe and the EU. Institute for European Environmental Policy (IEEP), Brussels, 40 pp.

Kumschick S, Bacher S, Evans T, Markova Z, Pergl J, Pyšek P, Vaes-Petignat S, Veer G, Vilà M, Nentwig W (2015) Comparing impacts of alien plants and animals in Europe using a standard scoring system. Journal of Applied Ecology 52: 552–561. https://doi.org/10.1111/1365-2664.12427

Lenzner B, Leclère D, Franklin O, Seebens H, Roura-Pascual N, Dullinger S, Essl F (2019) A framework for global 21st century scenarios and models of biological invasions. Bioscience biz070. https://doi.org/10.1093/biosci/biz070

López M, Altaba C, Andree K, López V (2010) First invasion of the apple snail Pomacea insularum in Europe. Tentacle 18: 26–28.

Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron D, Chan K, Daily GC, Goldstein J, Kareiva PM (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7: 4–11. https://doi.org/10.1890/080023

Nentwig W, Kuhnel E, Bacher S (2010) A generic impact-scoring system applied to alien mammals in Europe. Conservation Biology 24: 302–311. https://doi.org/10.1111/j.1523-1739.2009.01289.x

Palomo I, Múgica M, Piñeiro C, Martín-López B, Atauri J, Montes C (2017) Envisioning protected areas through participatory scenario planning: navigating coverage and effectiveness challenges ahead. Parks 23.1: 29–44. https://doi.org/10.2305/IUCN.CH.2017.PARKS-23-1IP.en

Parker IM, Simberloff D, Lonsdale W, Goodell K, Wonham M, Kareiva P, Williamson M, Von Holle B, Moyle P, Byers J (1999) Impact: toward a framework for understanding the ecological effects of invaders. Biological Invasions 1: 3–19. https://doi.org/10.1023/A:1010034312781

Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52: 273–288. https://doi.org/10.1016/j.ecolecon.2004.10.002

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8: 14435. https://doi.org/10.1038/ncomms14435

Thomsen MS, Byers JE, Schiel DR, Bruno JF, Olden JD, Wernberg T, Silliman BR (2014) Impacts of marine invaders on biodiversity depend on trophic position and functional similarity. Marine Ecology-Progress Series 495: 39–47. https://doi.org/10.3354/meps10566

Turbelin AJ, Malamud BD, Francis RA (2016) Mapping the global state of invasive alien species: patterns of invasion and policy responses. Global Ecology and Biogeography 26: 78–92. https://doi.org/10.1111/geb.12517

Vilà M, Hulme PE (2016) Impact of Biological Invasions on Ecosystem Services. Springer. https://doi.org/10.1007/978-3-319-45121-3

Walther G-R, Roques A, Hulme PE, Sykes MT, Pyšek P, Kühn I, Zobel M, Bacher S, Botta-Dukát Z, Bugmann H, Czúcz B, Dauber J, Hickler T, Jarošík V, Kenis M, Klotz S, Minchin D, Moora M, Nentwig W, Ott J, Panov VE, Reineking B, Robinet C, Semenchenko V, Solarz W, Thuiller W, Vilà M, Vohland K, Settele J (2009) Alien species in a warmer world: risks and opportunities. Trends in Ecology & Evolution 24: 686–693. https://doi.org/10.1016/j.tree.2009.06.008